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Christian Levers and Daniel Müller

1 The Globalisation of Agricultural Production

Globalisation has shaped land use for centuries, first through trade along the major land routes, such as the Silk Road, and increasingly via sea transport following the discoveries of Christopher Columbus and Vasco da Gama. The exchange of capital, goods, and services across international borders, including trade in agricultural commodities, gained fur-

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ther momentum in the mid-nineteenth century with the adoption of steam propulsion during the Industrial Revolution, which reduced freight costs (Harley 1988). However, the largest absolute increase in the volume of globally traded agricultural commodities occurred following the end of World War II and was mainly facilitated by trade liberalisation, urbanisation, and the drastic decline in international transport costs (Huwart and Verdier 2013). Particularly relevant for agricultural trade were the technological advances in international shipping, namely, the introduction of containerisation and specialised vessels for refrigerated transport that allowed for economies of scale and led to increased shipping volumes (Hummels 2007). The rapidly growing quantity and value of internationally traded agriculture and food products, often to distant places, provides evidence of the rise of globalisation in agriculture (Kastner et al. 2014). This rapid growth has resulted in an overhaul of the global food system and fundamental changes in global land use.

The globalisation of agricultural production is a prime example of how human and natural systems are coupled, often over large geographical distances (Liu et al. 2013; Friis et al. 2015). Consuming societies act as receiving systems by creating a demand for agricultural products that is not satisfied by domestic markets. This results in commodities being produced elsewhere, with farmers acting as the sending systems from where commodities are exported. International trade links the two systems and establishes the flow between telecoupled locations, which can lead to spillover effects between sending and receiving systems (see Chaps. 2 and 3). The telecoupling framework offers an analytical lens through which the globalisation of agricultural production can be analysed by assessing the related drivers, actors (and their interests), and physical resources.

The accelerating globalisation of agriculture, with its associated rise in the volumes and values of agricultural products that are internationally traded, results in increasingly telecoupled production systems, especially in regions where a large share of production is destined for export (MacDonald et al. 2015). The large spatial footprint of export-oriented agriculture is responsible for substantial environmental costs, including negative local (on-site) effects, such as soil degradation, regional impacts due to excessive freshwater use or nutrient and pesticide runoff, and global concerns, such as carbon emissions and biodiversity loss due to the conversion of land for export-oriented commercial agriculture (see Chaps. 2 and

3). Indeed, the globalisation of agriculture is a major driver for the tropical deforestation that has occurred over the last 50 years and its related greenhouse gas emissions and biodiversity losses. A large share of the tropical deforestation that has occurred to date has fuelled capital-intensive and export-oriented agriculture, such as the expansion of soybean production in Latin America or of tree crops in Southeast Asia (Malhi et al. 2014).

The environmental costs associated with the expansion of export-oriented agriculture are of increasing societal concern. International trade in agricultural commodities externalises the environmental costs by shifting the burden from the places of consumption towards the places of production of the exported commodities (Hoekstra and Wiedmann 2014). Consequently, policies that aim at globally sustainable land use need to account for the land-use footprints embodied in consumption that occur at the sites of production. One economically efficient strategy for doing so is to quantify the environmental costs of production and impose consumption taxes that account for the size of the negative externalities. However, quantifying the costs is difficult and tax implementation is obstructed by political hurdles. Another approach to linking production externalities with consumption is the use of labels that detail the land-use footprint of the products. The aim of such labelling is typically to achieve voluntary reductions in the consumption of products that cause environmental costs elsewhere. However, quantification of the production footprints necessitates tracking the value chain from consumption to production (see Chaps. 6, 7, and 8).

Increasing trade in agricultural commodities altered the spatial configuration of global land use, which underlines the important role of the globalisation of the agricultural sector in driving telecoupled land-use dynamics. In particular, the emergence of production regions that are dominated by export-oriented land uses substantially influenced land systems (Lambin and Meyfroidt 2011). These production hotspots of export-oriented agriculture are typically restricted to a small number of key agricultural commodities that are designated for international markets and generate most of the region's agricultural revenue (e.g., soybean meal in the Neotropics or palm oil in Indonesia). Delineating the emerging spatial configurations of export-oriented agricultural production, including their extent, location, and key commodities, can help in assessing the spatial clustering of export production and its associated environmental trade-offs.

To assess the land-use footprint of exported agricultural commodities, data on the extent of the domestic land use that is devoted to exports and estimates of where the domestic export production takes place are necessary. The share of a nation's total crop production that comes from export crops can be extracted from Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) data for every year since 1961. However, the land-use footprint of export-oriented crop production has, to the best of our knowledge, never been assessed globally or at a subnational scale. This is unfortunate because estimations at fine spatial scales permit a better assessment of the spatial footprint of land use devoted to export crop production and allow for a more accurate assessment of the social and environmental effects of agricultural exports.

In this chapter, we spatially delineate the land footprint of export-oriented crop production for major global export crops using the telecoupling framework to combine flow- with place-based analysis (Friis and Nielsen 2017). By developing a spatial allocation algorithm that approximates a region's likelihood of being dominated by export production, we go beyond traditional approaches that assume the proportionality of patterns, rates, and volumes between export production and overall production. Our allocation algorithm generates global, crop-specific maps that depict the share of crops produced for export in 2005. The maps demonstrate the effect of telecoupling on agricultural production by showing the effect that the international trade of agricultural commodities has on land use in the producing regions. Knowing the type and original location of export crops at a subnational scale allows for a better approximation of their environmental and social costs, which can, in turn, help to raise the primary importing countries' awareness about the impacts of their consumption. Such analysis thus informs policy-making, influences consumer preferences, and stimulates design and supply-chain interventions that can assist in steering telecoupled systems towards sustainability (see Chap. 6). The algorithm also has the ability to identify export crop production hotspots that underlie the analysis of the positive and negative place-based consequences of the increasing focus on exports in commercial agriculture. By identifying the regions and commodities for which telecouplings typically manifest, the analysis can pinpoint the producing regions (by crop) and commodity flows that are strongly linked by telecoupling. In that way, our approach highlights source regions of telecoupled systems that warrant prime attention for telecoupling research.

2 The Major Global Export Crops

The global area harvested for all crops, as reported by FAOSTAT (FAO 2018), increased by 724 million hectares (Mha) between 1961 and 2016, an increase of 26%. Over the same period, the harvested areas of the 13 crops with the largest areas dedicated to export (according to data from 2005, our year of analysis) increased by 325 Mha (55%). The expansion of export crops was therefore responsible for 45% of the net increase in total area harvested since 1961.

We focus our subsequent analysis on the most important export crops, which we define as those crops with the largest harvested area devoted to export in the year 2005. To do so, we use updated data from Kastner et al. (2014), who exploited bilateral trade matrices from FAOSTAT to link consumption to the product's point of origin, following the approach of Kastner et al. (2011). Figure 5.1 depicts the changes in the harvested areas of the 13 selected crops. Maize showed the largest increase in harvested area between 1961 and 2016, with an increase of almost 82 Mha (77%): this expansion alone is equivalent to 25% of the total net increase in the harvested areas of the 13 major export crops. The increase in the global harvested area of wheat is much smaller, at 16 Mha (8%) over the 56-year period. The area harvested for barley actually declined by 8 Mha (14%) over the same period. Figure 5.1 also reveals a steady increase in the area devoted to the cultivation of non-staple crops, such as cacao, sugar crops, and rubber. Similarly, the most important oil crops (soybean, rapeseed, oil palm, and sunflower) gradually occupied a greater area during this period. Overall, the increase in harvested area is much larger for non-staple crops than for staple crops, and the same is true for the quantities the crops produced (Rueda and Lambin 2014).

Figure 5.2 summarises the total area harvested for export in 2005 for the 13 selected crops, using the data from Kastner et al. (2014). Soybean and wheat clearly dominate global export production in terms of area harvested, with approximately 50 Mha each, followed by the coarse-grains maize (17 Mha) and barley (12 Mha). The other export crops occupy between 5 and 8 Mha and include oil crops (rapeseed, sunflower, and oil palm), tree crops (cocoa, coffee, and rubber), as well as sugar, paddy rice, and cotton. Tree crops exhibit the highest share of the area

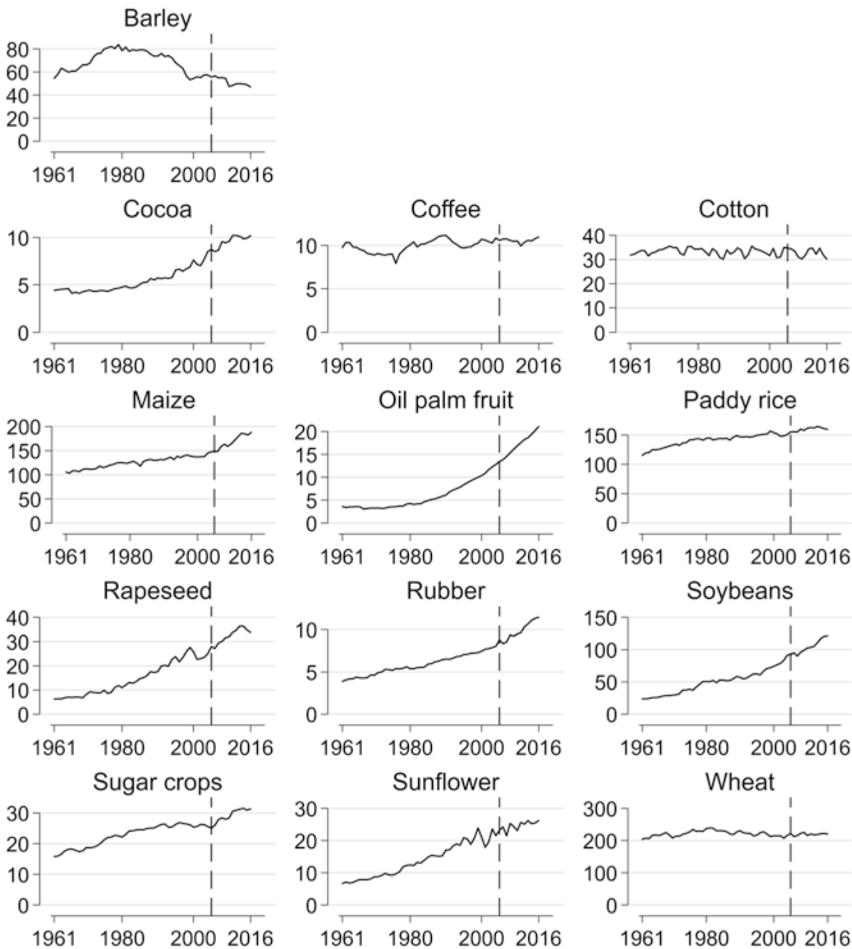

Fig. 5.1 Increase in area harvested in million hectares (Mha, y-axis) of the major export crops (in alphabetical order). Data are from FAO (2018) and the vertical line indicates the year 2005 for which we conducted the spatial allocation. Note the different scales on the y-axis

devoted to export production (right axis in Fig. 5.2) at 85% (cocoa), 75% (rubber), and 68% (coffee). Around 25% to 55% of the total area harvested for oil crops (soybean, oil palm, rapeseed, and sunflower) was devoted to exports in 2005. Conversely, less than a quarter of the area

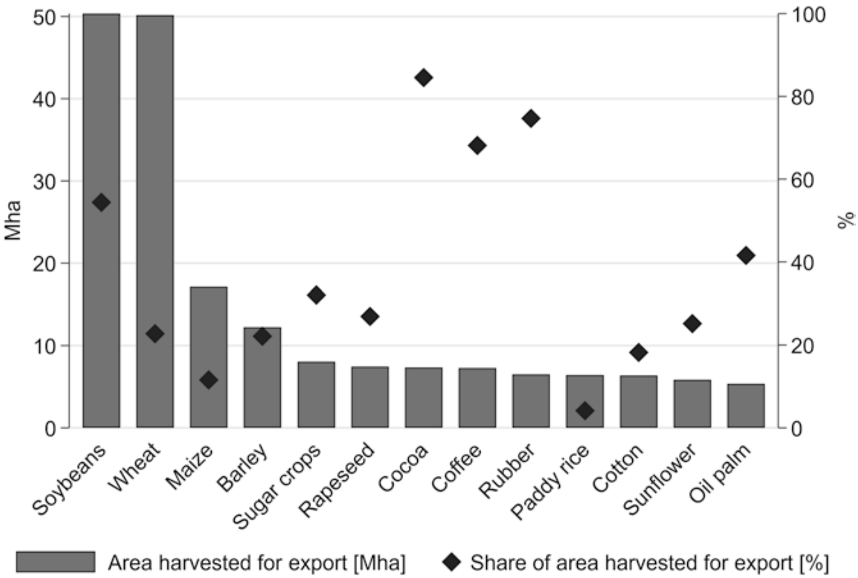

Fig. 5.2 Absolute area harvested for export (Mha) and share of area harvested for export (%) of the 13 most important export crops. Data are from Kastner et al. (2014), based on FAOSTAT

harvested for cereal crops was traded internationally, of which paddy rice was the lowest (4%).

Overall, the absolute and relative values of the area harvested for the 13 most important export crops present a mixed picture (Fig. 5.2). Large proportions of the key staple crops, wheat and maize, are traded internationally. Large areas of oil crops (mainly soybean) are also dedicated for export, mostly to feed monogastric livestock herds in distant places (Eitelberg et al. 2017). The major export crops in our analysis included crops that grow best in temperate conditions (wheat, barley, and rapeseed), as well as crops that originate from subtropical and tropical regions (cocoa, coffee, and oil palm). Similarly, the list includes both staples (wheat, maize, and rice), as well as crops that are non-essential for balanced nutrition, the so-called luxury crops (soybean, sugar, coffee, and rubber).

3 Spatial Allocation of Export Crops

3.1 The Allocation Approach

We used the most recent crop data available (2005) from the Spatial Production Allocation Model (MapSPAM) as our cropland layer (You et al. 2014b). MapSPAM downscales subnational agricultural statistics for harvested area and yields for 20 crops and 6 production technologies (irrigated, rainfed with high inputs, rainfed with low inputs, rainfed subsistence, all rainfed, and all technologies combined). The downscaling approach employed in MapSPAM uses entropy optimisation and accounts for crop-specific biophysical conditions, population density, and crop prices to distribute cropland in a spatially explicit way, with a grid cell size of approximately 10 × 10 km (You et al. 2014a, b). We excluded rubber from the crops that we mapped because no suitability data are available for rubber from the Global Agro-Ecological Zones (GAEZ) data that we used as the suitability layer for crop production in the allocation algorithm. This is unfortunate because 6.5 Mha (75%) of the total 8.7 Mha of area harvested for rubber were dedicated for export in 2005 (Fig. 5.2).

We allocated the crop-specific harvested areas from MapSPAM for the year 2005 based on an index representing their likelihood for export-oriented crop production. We created one likelihood index for each of the twelve selected export crops by combining data from three indicators: (1) crop-specific land suitability (IIASA and FAO 2012), (2) field size of cropland (Fritz et al. 2015), and (3) accessibility to cities with more than 50,000 inhabitants (Nelson 2008). The assumption in the selection of these indicators is that most export production is driven by profit-seeking behaviour and hence is concentrated in areas with high natural suitability, relatively large agricultural fields, and relatively large farms (unfortunately, spatially explicit data on farm size is lacking) (Neven et al. 2009). For the same reason, export-oriented agriculture tends to cluster close to populated places where access to trade hubs facilitate international trade (Iimi et al. 2015). We used the "high input/advanced management" version of the crop-specific suitability data, which assumes that the farming systems are mainly market-oriented with commercial production as the main management objective—a realistic assumption for the majority of the export-oriented crops. Under this assumption, crop production uses improved high-yield varieties, is capital intensive and mechanised, has low labour intensity, uses appropriate applications of nutrients, and applies pest, disease, and weed control (IIASA and FAO 2012).

We min-max-transformed all the indicators to a range between 0 and 1, thereby maintaining their original data distribution. We then calculated the sum of the three likelihood indicators per grid cell to derive the crop-specific likelihood index that quantifies the propensity of a grid cell to be allocated to the production of a specific export crop. The likelihood indices represent the likelihood of export crop production in additive fashion, without weights applied to any of the three likelihood input indicators. We tested the ability of the likelihood indices to capture the export crop production by calculating the correlation between the mean likelihood index and the actual export share per country for each crop (Fig. 5.3). Overall, the relationship between the likelihood and the export share was positive and high, with a correlation coefficient of $\rho = 0.42$. The correlation was especially high for cereals (barley $\rho = 0.65$, wheat $\rho = 0.56$) and oil crops (rapeseed $\rho = 0.69$, sunflower $\rho = 0.60$) but was moderate for the remainder of the crops. The exceptions were cocoa and coffee, for which negative correlations were calculated. The suitability surfaces for these tree crops are apparently not adept at capturing cropping patterns. In the case of coffee, this is likely because the two main coffee species, Arabica and Robusta, are subsumed in one suitability layer despite their different agro-ecological demands. The negative correlation between the likelihood index and the export share in the case of cocoa might reflect the relative tolerance of the cocoa plant, which grows in most hot and humid tropical areas.

We derived the total harvested area and the area harvested for export crop production for each crop and country from the data of Kastner et al. (2014). We then calculated the crop- and country-specific shares of the areas harvested for export. The area demand of export crop production was calculated for each crop and country individually by multiplying the share of exported crop production (see above) with the harvested crop area from MapSPAM (aggregated for each country). We verified the agreement between the harvested crop areas from MapSPAM and the

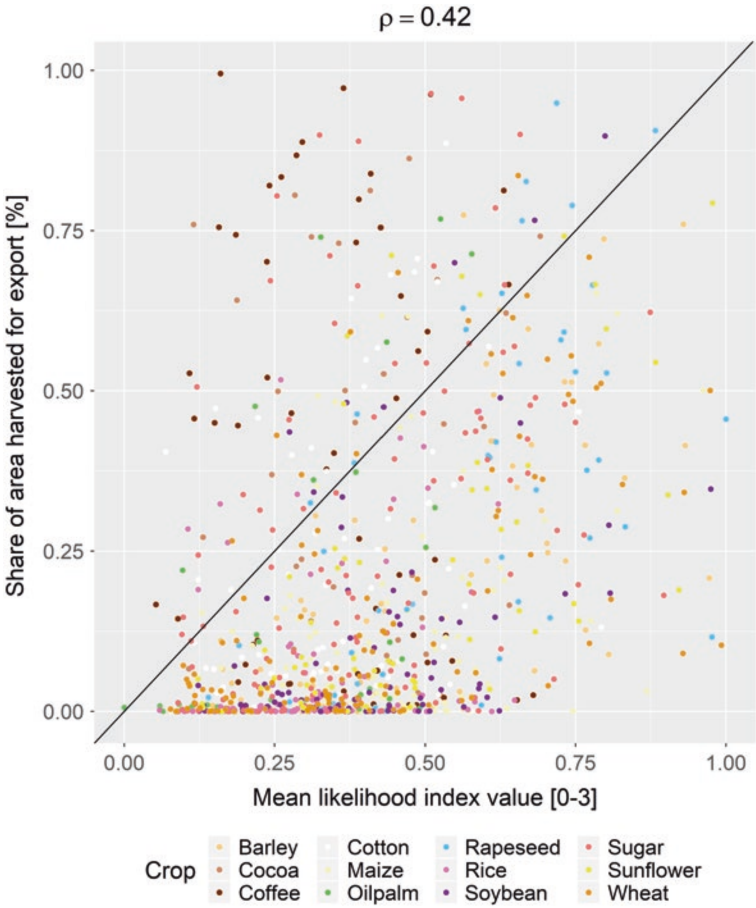

Fig. 5.3 Share of area harvested for export (%) in relation to the mean likelihood index [0–3] for all crops by country (N = 999). The Spearman correlation coefficient ρ is provided in the title. Note that export share values exceeding 100% (N = 36) were excluded

data from Kastner et al. (2014) based on FAOSTAT to ensure that the allocated harvested areas cover the actual export areas for each country and crop (correlations were larger than ρ = 99 for all crops).

We then spatially allocated each crop within each country by selecting the grid cell with the highest index value from our crop-specific likelihood index for export (see above) and defined this grid cell as destined for export. The allocation process stopped when the entire crop-specific export demand was allocated. We cross-checked whether all demand in the statistical data was allocated by comparing the sum of the harvested area for export production with the maps of the allocated demand (the differences were minor and ranged between 61 ha for rapeseed and 676 ha for rice).

Our allocation scheme resulted in binary classifications that contained grid cells, which were either categorised for export (i.e., the grid cell was selected by the allocation routine due to its high likelihood index) or not. As the area harvested for export has to be equal to or lower than the total area harvested for each crop, our approach always allocated the entire demand to the grid cells, starting with the highest likelihood index value and descending from there. We used these binary layers as masks to obtain the actual harvested area of each crop from the MapSPAM data. We calculated area shares for each crop by dividing the harvested area (in hectares) within each grid cell by 10,000 (the approximate size of a 10 × 10 km MapSPAM grid cell in hectares). Finally, we calculated the sum of the area shares for all 12 crops to obtain and to map the overall harvested area within a given grid cell that was destined for export. We further created a categorical map of the dominant crop type destined for export within each grid cell.

3.2 Caveats of the Allocation Algorithm

The resulting maps yield an interesting general spatial representation of the footprint of export-oriented agriculture, yet the spatial details must be interpreted with care. First, we used MapSPAM data from 2005, which were the most recent MapSPAM data available to us at the time of writing. However, both the harvested area dedicated to non-staple crops and the share of these crops being exported has continued to grow since 2005 (cf. Fig. 5.1). Our maps therefore represent a conservative illustration of the extent of the footprint of global export crops. Moreover, the available data only allowed for mapping a single point in time; we were therefore unfortunately unable to assess the temporal dynamics of the spatial footprint of global export crop production.

Second, we used ad hoc rules for the spatial allocation of export-oriented agriculture within countries. While this yields a useful qualitative and visual impression of the spatial footprint of crop exports, it does not allow for a cell-by-cell validation of the locations within countries where harvested areas likely to be used for export are concentrated. Uncertainties in the spatial allocation arise because the share of exports is only available from FAOSTAT at the country level and because the data we used to characterise the commercial orientation of export-oriented crop production are coarse and marred by uncertainty. We also cannot account for within-country crop trade or for the share of within-country commercial agricultural production that is destined for domestic consumption.

Third, our spatial allocation strongly depends on the quality of the input data, and especially on the MapSPAM data and the FAO trade statistics. MapSPAM data is extensively evaluated by several institutions for plausibility (see You et al. 2014b), yet these evaluations were mainly qualitative or semi-quantitative in nature. We are only aware of one independent and quantitative assessment of the MapSPAM data by Tan et al. (2014), who compared the accuracy of the crop maps with empirical case study results for China and found a satisfactory agreement. Regarding the FAO trade data, we rely on the data from Kastner et al. (2014) that circumvents the common problem of bilateral trade data by tracing the primary origin of imported agricultural produce, linking crops to their actual places of consumption. These data are a seminal and well-established product for trade flow data. However, FAO data may suffer from the misreporting of trade statistics from some countries and, by definition, only contain trade that was officially registered.

Fourth, our examination of global export-oriented crop production fails to account for the important role of the livestock sector in driving telecoupled land-use dynamics. Although our trade data includes a (rough) estimate of cropland used for feed, embodied in meat exports (e.g., maize used as feed for German pork exports), pasture areas are not included. However, enormous land resources are used for livestock grazing, particularly in South America, where a large increase in meat exports was correlated with a dramatic increase in pasture areas (Aide et al. 2013). Moreover, the assessment of the land-use footprint of meat production is challenging because data on pasture use and fodder production are often not available and, when available, are marred by uncertainties, which further complicates tracing the origins of livestock production.

Finally, telecouplings as empirical, global-scale phenomena complicate a holistic assessment of the place- and flow-based processes of global export agriculture. Our analysis does not disentangle the underlying causes that drive the export patterns and thus the land uses in distant places (see Chap. 6). Nor could we identify the spatial linkages between production locations and end-consumption or land-use spillovers and displacements. Such information would be a crucial addition to our crop export maps and would permit a better understanding of telecoupled food-production systems.

4 Spatial Patterns and Hotspots of Exported Crop Production

4.1 Spatial Patterns of Crop Production for Export

Crop production predominantly destined for export in 2005 was clearly concentrated in few regions: the Midwestern US and south-central Canada, the Chaco, Cerrado, and Southern Amazonia in South America, Central and Eastern Europe, and the southern part of West Africa, as well as Southeast Asia and southern Australia (Fig. 5.4, top panel). The highest export shares of the total harvested area can be found in the US, Argentina, Brazil, Ukraine, and Australia. With regard to crop type groups, such as cereals or oil crops, strong spatial clustering is apparent (Fig. 5.4, bottom panel). Cereals dominate the temperate climate regions of the Northern Hemisphere (except for wheat in Australia and rice in Pakistan) and tree crops dominate along the Equator. In contrast, oil crops show diverse spatial patterns, with soybean exports particularly clustered in South America (but also in North America and India), rapeseed in parts of India and Poland, and sunflower in Central and Eastern Europe.

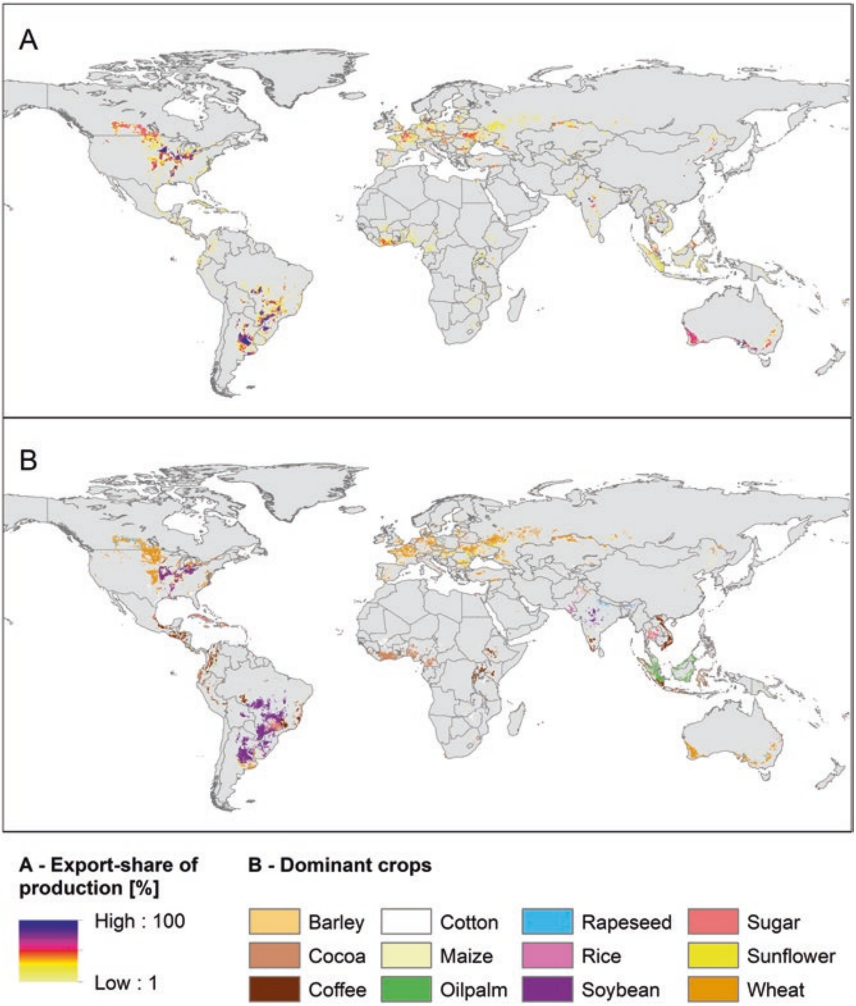

Fig. 5.4 Share of harvested area (**A**) and main crops (**B**) devoted to export crop production

4.2 Hotspots of Individual Export Crops

Investigating the shares of the harvested areas destined for export per grid cell provides distinct, crop-specific spatial patterns. The most visually striking pattern in the map of the dominant export crops (Fig. 5.4) are the large areas of soybean (the crop with the largest exported harvested area globally; cf. Fig. 5.2) in South America, and in particular, the western and central region of the Brazilian Cerrado, the northern part of the Pampas in Argentina, the south-western part of the Atlantic Forest in Brazil and Paraguay, as well as the Argentinian and Bolivian parts of the Chaco. The second largest global hotspot of soybean production destined for export is located in the northern Midwestern states of the US. Central India hosts another hotspot of export soybean production, but with a much smaller area than the hotspots of South and North America.

In terms of cereal production, wheat exports are concentrated in the large breadbaskets of the temperate zone, including the wheat belts in the US (Montana, North Dakota, South Dakota, and Minnesota), Canada (Saskatchewan, Alberta, and Manitoba), Australia (Western Australia, South Australia, New South Wales), France, Germany, and across the large black soil areas of the former Soviet Union (i.e., Russia, Ukraine, and Kazakhstan). Smaller hotspots can be found in parts of the Czech Republic, Hungary, and Turkey, and in the Pampas and Chaco regions of Argentina.

Maize exports mainly originate from the US (Great Lakes region, Minnesota, and Iowa) but also from the Pampas and Chaco regions in Argentina and the south-western region of the Atlantic Forest (Brazil, Paraguay), as well as parts of France, Ukraine, and smaller regions in Hungary, Bulgaria, and northern China (Jilin, Heilongjiang). Barley is mainly exported from European Union (EU) countries, in particular France, Germany, and Denmark, but also from parts of Ukraine and Canada (Saskatchewan, Alberta, and Manitoba), and from the wheat belt of Australia (Western Australia, South Australia, and New South Wales).

Harvested areas of sugar production used for export, including sugar cane and sugar beet, are predominantly located in the Brazilian Cerrado, the Central American countries, the Greater Antilles (Cuba, Dominican Republic), central and northern India, and several countries of the EU (e.g., northern France, central and north-western Germany, western Poland), as well as Ukraine and Belarus. Rapeseed cultivated for export shows distinct hotspots in Canada (Saskatchewan, Alberta, and Manitoba), Central and Eastern Europe (France, Germany, the UK, Czech Republic, Poland, Hungary, and the Baltic countries), northern India, and, to a lesser degree, in the wheat belt of Australia.

The areas cultivated for tree crop exports were mainly concentrated in the tropics and subtropics. The land-use footprint of exported coffee cultivation (almost 70% of total global area cultivated for coffee goes into export; cf. Fig. 5.2) shows clusters in parts of Brazil (mainly in Minas Gerais and Rondônia), Colombia, Central America, and eastern Africa, and in much of Vietnam, where the Robusta variant dominates. Exports of palm oil are seen in the large and well-known land-use footprints in Malaysia and Indonesia, with particularly drastic environmental consequences due to the high greenhouse gas emissions and the high levels of endemic species that are threatened by the expansion of export-oriented oil palm cultivation (Carrasco et al. 2017). Cocoa is the most important export crop in western Africa and has a substantial footprint in Ecuador (cf. Figs. 5.4 and 5.5). Large shares of the harvested areas of Indonesia, Malaysia, and Vietnam are tree crops destined for export (particularly palm oil and coffee), but this pattern is likely an artefact of the 2005 MapSPAM data. Despite known spatial clustering, such as the hotspot of Vietnamese coffee production in the Central Highlands (Meyfroidt et al. 2013), the harvested area of these crops are relatively homogeneously distributed across very large areas in the MapSPAM data.

We also stratified our allocated harvested areas of export-oriented crop production by global biomes (Olson and Dinerstein 2002). Figure 5.6 reveals that the largest area used for export is located in the "Temperate Grasslands, Savannahs and Shrublands" biome (ca. 52 Mha), followed by the "Temperate Broadleaf and Mixed Forests" biome (ca. 44 Mha), and the "Tropical and Subtropical Moist Broadleaf Forests" biome (ca. 33 Mha). The biomes with lower but still substantial export crop cultivation include the "Tropical and Subtropical Grasslands, Savannahs and Shrublands" (ca. 19 Mha), the "Mediterranean Forests, Woodlands and Scrub" (ca. 11 Mha), and the "Tropical and Subtropical Dry Broadleaf Forests" (ca. 10 Mha). The remaining biomes had less than 5 Mha of harvested areas destined for export.

Wheat, soybean, and maize production (and to a smaller degree barley) contributed the largest share of the area harvested for export in the "Temperate Broadleaf and Mixed Forests" biome and the "Temperate Grasslands, Savannahs and Shrublands" biome, which cover large parts of the US, Central and Eastern Europe, and Central and East Asia. The

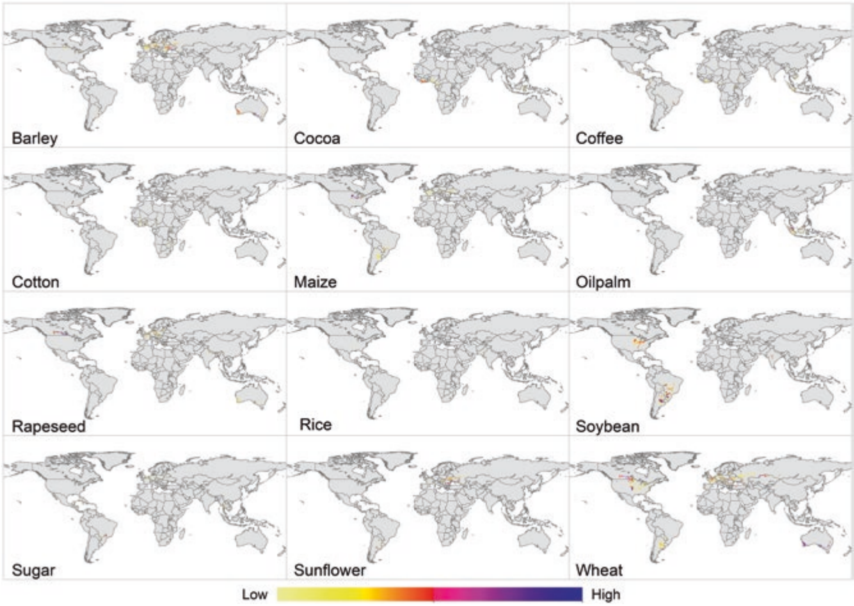

Fig. 5.5 Hotspots of crop area harvested for export. Value ranges have a common minimum of 1% for all crops but crop-specific maximum values. Maximum values are 34% (barley), 85% (cocoa), 85% (coffee), 67% (cotton), 78% (maize), 41% (oil palm), 38% (rapeseed), 100% (rice), 82% (soybean), 78% (sugar), 26% (sunflower), and 100% (wheat). Due to the fixed grid-cell size of 10 × 10 km, the relative values also represent absolute area estimates (e.g., cotton: 67% of a 10 × 10 km [i.e., 100 km^2] grid cell is equal to 67 km^2)

"Tropical and Subtropical Moist Broadleaf Forests" biome, which covers the northern part of South America, equatorial Africa, and Southeast Asia, was predominantly characterised by tree crops (cocoa, coffee, and oil palm) that accounted for more than half of the harvested area. The remaining areas were mainly dedicated to soybean, sugar, and rice production. The areas harvested for export within the "Tropical and Subtropical Dry Broadleaf Forests" and the "Tropical and Subtropical Grasslands, Savannahs and Shrublands" biomes were mostly dedicated to soybean production and were predominant in the Chaco (Argentina) and the Cerrado (Brazil) in South America, large parts of Sub-Saharan Africa, and northern Australia. The major export crops from the "Mediterranean Forests, Woodlands and Scrub" biome are cereals, mainly wheat but also

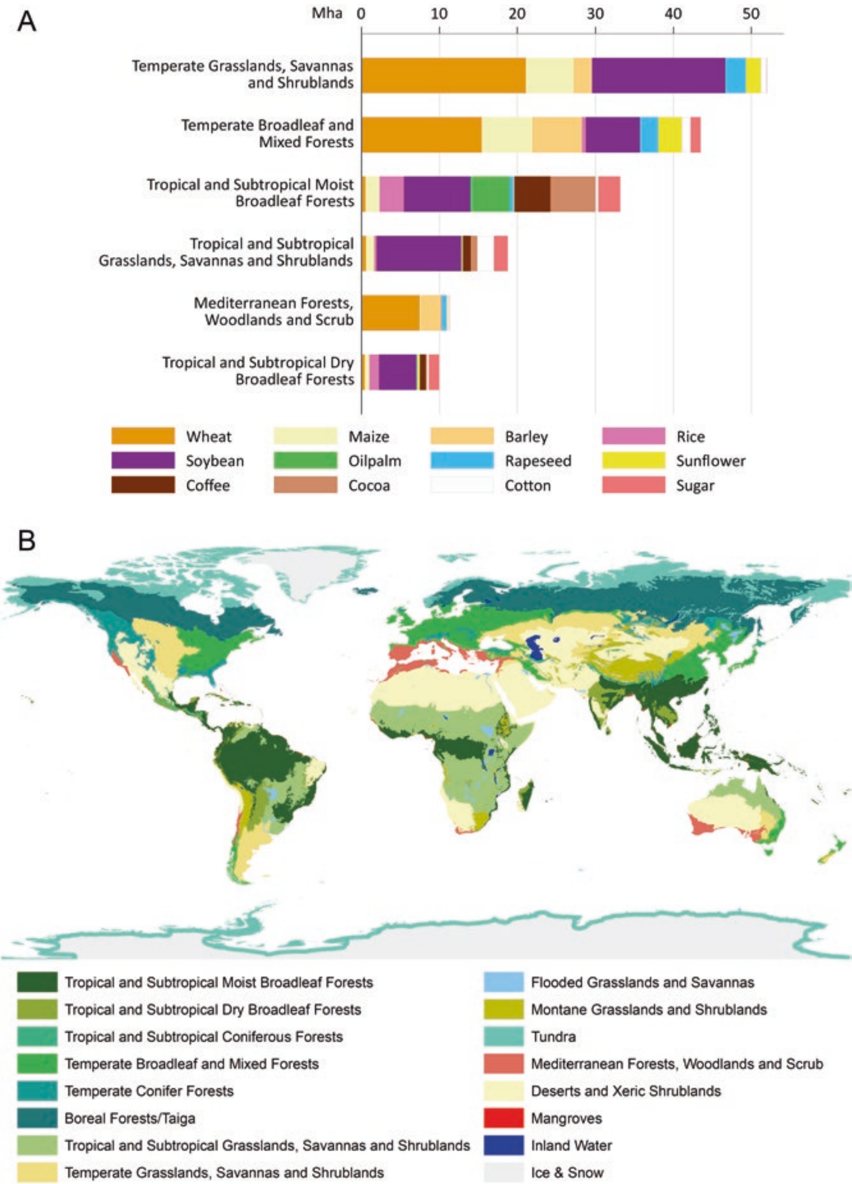

Fig. 5.6 Decomposition of crop area harvested for export by terrestrial ecoregion (biome) (panel A). Only biomes with more than 5 Mha of allocated export-oriented crop production are shown. Panel B shows the spatial distribution of the terrestrial ecoregions of the world (Olson and Dinerstein 2002)

barley. Cereal exports originate from many countries of the Mediterranean region, in particular, from Spain, Italy, Greece, West Turkey, Morocco, and Algeria.

5 Effects of Growing Export Crops on Food Systems and the Environment

The globalisation of agriculture has resulted in enormous increases in the amount and value of agricultural commodities that are traded internationally. In particular, the last 50 years have seen unprecedented acceleration in agricultural commodities produced exclusively for export. The rising volume of international trade has contributed to improved diets by providing better access to nutrition, in particular for food importing countries (Wood et al. 2018). At the same time, the growing globalisation of agricultural production facilitated the transition towards diets with a higher proportion of saturated fats, sugars, animal-sourced products, and processed foods (Popkin 1993). However, the impacts of agricultural globalisation not only affected consumption opportunities (see Chap. 6) but also overhauled production systems. With an increasing focus on export, food production became more commercialised and capital intensive, farm sizes increased, and farms concentrated on a smaller number of crops that generated the highest profits (Graesser et al. 2018; Reardon et al. 2009).

We examined land-use footprints associated with export-oriented agriculture at the point of product origin. We mapped the global centres of agricultural export production for 12 major export crops. To do so, we allocated the crop-specific harvested area destined for international trade by combining global cropland maps and spatial layers capturing the crop's suitability for export. The results demonstrate the high concentration of export crop production in Latin America, the US, and Southeast Asia and provide visual confirmation that much of the world's farmland is dedicated to a few, high-value crops. Our analysis also identifies specific crop-country combinations that are characterised by high degrees of telecoupling. We used data from 2005, which were the latest data available at the time of writing. Since then, the degree to which agriculture is globalised has continued to increase (cf. Fig. 5.1). For example, global meat production has increased by 238 million tons (Mt) to 1343 Mt and almost a quarter (58 Mt) of this additional production was exported (FAO 2018). The increase in the global meat trade has considerable land-use implications (see Chaps. 2 and 3), such as the stimulation of soybean trade, because soybean meal is the major protein source in the diets of monogastric livestock. Moreover, much of the increase in global livestock trade arguably comes from the expansion of pastures. This implies that including grazing lands when calculating the impact of livestock production would further elevate the spatial footprint of export agriculture.

The growing land-use footprint of consumption is of great societal concern because of the associated environmental impacts on regions where this demand has been met through expansion or intensification of production (Carrasco et al. 2017). In temperate regions, suitable land resources have long been used for agricultural production, therefore, most of the expansion of agricultural production in recent decades took place in tropical and subtropical regions, where large stocks of carbon are captured in the vegetation and where species richness is high. Another example of an environmental impact that has been well documented is the large amount of water that is required for the production of internationally traded agricultural products despite the fact that many of these traded products originate from water-scarce regions (Dalin et al. 2017; Konar et al. 2011). Awareness of the effects of agricultural production on foreign lands is becoming increasingly prominent among the consumers in importing countries, and recognition of the natural resources that are embedded in the traded agricultural commodities is rising.

The growing importance of food trade has implications for domestic food security in the countries that rely on imports, and particularly in countries that rely on imports of staple food commodities. The growing reliance on imports can result in undesirable social and ecological outcomes, as evidenced by the food cost crises of 2007 and 2011 that highlighted the geopolitical implications of import dependence (Bren d'Amour et al. 2016). Co-occurring adverse weather conditions reduced cereal yields in key exporting regions, resulting in export restrictions. These, in turn, contributed to spikes in wheat prices, which had detrimental consequences for the food supply and food security in the importing countries. High prices for food staples have, for example, adversely affected countries in the Middle East, which heavily rely on wheat imports, and may have been a potential trigger for the Arab Spring (Bren d'Amour et al. 2016; Lagi et al. 2011).

Telecoupled land systems can also be an impetus for conservation by improving the flow of global information and triggering new policies in food production systems, such as codes of conduct or certification schemes, that can improve food security and livelihoods (Eakin et al. 2017, see Chaps. 9, 12, and 15). For example, international markets and financial institutions increasingly pressured soybean producers in the Brazilian Amazon for higher environmental and social standards, and this consumer pressure eventually resulted in the implementation of the soybean moratorium, a voluntary zero-deforestation agreement (Gibbs et al. 2015). Anticipating the impacts of export-oriented agriculture is of increasing importance because it informs the growing numbers of consumers that are concerned about the environmental and social implications of their consumption patterns. Better place-based insights on the land-use footprints of consumption may support the implementation of voluntary schemes as well as compulsory regulations that aim at more sustainable land use.

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